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Gabriola's glacial drift—innocent earthquakes?

Nick Doe

One of the exciting things to happen while doing scientific research is to discover some completely unanticipated connection between sets of observations that were originally made for unconnected reasons. And so I have to record that, just by chance, at the time I was investigating glacial erosion patterns in the landforms of Gabriola, I was asked to give a talk to emergency responders on Gabriola on earthquakes and the dangers they pose.[1]

In the course of preparing a PowerPoint presentation for this, I casually threw in some pictures of rockfalls, the point being that one of the obvious hazards of a major earthquake is that there will be rockfalls on the island and that these will damage buildings and will block roads.

Now, minor rockfalls from steep inclines happen all the time due to on-going weathering of the rock, but we also have here evidence of prehistoric rockfalls involving huge boulders, some weighing several hundred tonnes. And the usual suspect is of course earthquakes. The only question in my mind was, did these falls occur during the last megathrust earthquake on January 26, 1700, or is the debris we see the cumulated debris from several or many earthquakes.

This question could be resolved by radiocarbon dating the remains of crushed vegetation likely existing underneath some of the bigger boulders. All it needs to resolve this is some heavy duty lifting equipment and a few hundred dollars for lab tests.

After the presentation, I had a conversation

Boulders—big ones—in the backyards along the base of the cliff at Harrison Way on Gabriola. Usually blamed on earthquakes, but perhaps they are in fact a legacy of the last ice age.

[1] Gabriola Emergency Social Services (GESS) event, May 7, 2011.

with Tom Cameron,[2] who at the time was unaware that I was at that moment so engaged in ice-age Gabriola, and he commented that he thought there was something odd about the huge boulders at the bottom of the cliffs along Harrison Way, pictures of which I had shown in the presentation. They almost appeared, remarked Tom, to have been gently lowered into place. Oh! my gosh. There are two things that I could think of that could have done that. Either the boulders had been slowly lowered into place on the surface of melting ice, or, Harrison Way had been at the time of their fall at, or below, sea level. Either way, recent earthquakes were not to blame.

Tom's subsequent e-mail on the topic is, I think, worth quoting in full.

June 5, 2011

> …. When Nick and I were originally talking, bouncing around from topic to topic; I was thinking of my experience with boulders in the major meltwater channels of Saskatchewan. As children we used to roll boulders, as big as we could manage with our bare hands, from the top of banks. It was amazing to me that a 600-pound [0.3 tonne] boulder with considerable vertical and horizontal acceleration—500 feet [150 m] or so—would pound right though young aspen forests. I remember being a little alarmed that maybe we would take out a house or car below.
>
> I did observe to Nick that in my experience in Alberta, I never saw big rocks at the base of cliffs. On Gabriola, it always struck me that the big rocks at the base of cliffs looked out of place and I wondered why they didn't continue on to the bottom of the hill below Harrison Way [and on to Descanso Valley Drive]…..Tom Cameron.

And so was borne a new theory. The large boulders are not the result of earthquakes, but were formed by "plucking" at a time when the whole scarp face was under ice that was moving slowly across the valley from the northeast. As the ice subsequently halted and wasted away, the boulders were gently lowered to the base of the slope. Hence the lack of signs of any impacts.[3]

Big boulders at the base of cliffs

A look at this new idea.

Harrison Way

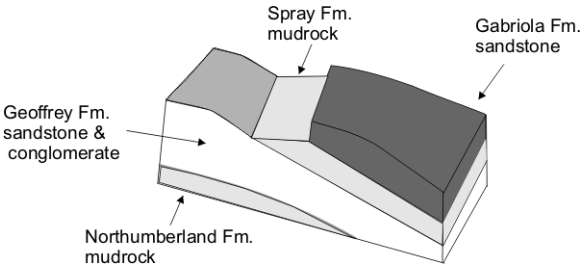
The Descanso Valley in the corner of Gabriola closest to Nanaimo runs N24°W toward the sea. This makes it certain that it was carved out by ice exploiting the C3 longitudinal fold fractures (N25°W, ±14°) that run parallel to the axis of the island's syncline at the north(west) end of the island.[4] Differential erosion of the Spray Fm. and Northumberland Fm. mudrock has likely undercut the sandstones and conglomerates to form both the valley and Northumberland Channel sea-cliff escarpments.

Because the valley is oriented toward the northwest, it must have already been in existence by the time ice began moving from the northeast during the last ice age.

[2] Tom Cameron is a plant ecologist with a background in municipal, provincial, and national park management. He lives on Gabriola and is a past-president of the Gabriola Land and Trails Trust (GaLTT).

[3] A rock falling freely will theoretically reach a velocity of 100 km/hr. after just 40 metres. Its kinetic energy at that point would be about 0.1 kg or half a stick of TNT per tonne. Some of the boulders along Harrison Way easily exceed 300 tonnes.

[4] These fractures also follow the general orientation of the coastline south of Gabriola while the similar C1 set follow the general orientation of the coastline north of us. They date back to the Eocene. Doe, N.A., *The orientation of fractures on Gabriola*, *SHALE* 20, pp.41–55, April 2009.



Left: The structure of the Descanso Valley [NOT TO SCALE]. The valley is a cross-section of a limb of the syncline (shallow U-shaped fold) whose axis runs along the central axis of the island off to the right in this sketch.

Above: The Descanso Valley in the southwest corner of Gabriola looking N24°W toward Descanso Bay.

The boulders discussed in the text are along the uphill side of Harrison Way, which follows the bench at the contact between the Spray and Gabriola Fm. They lie about 40 m ASL, 25 m above the valley floor, and 65 m down from the crest of the scarp.

So this ice must have moved up the inclined sandstone of the Gabriola Formation before encountering the drop off into the valley. Similarly, the ice must have continued to move up the inclined gritty sandstone and conglomerate of the Geoffrey Formation before encountering the drop-off into the sea (the Northumberland Channel). Both of these southwest facing drop-offs were thus in situations resembling those of the lee sides of *roches moutonnées*. The question is then, could the huge boulders alongside Harrison Way be the result of sub-glacial plucking and not, as is generally surmised, earthquakes?

Some additional pertinent observations are:

- the boulders are located very close to the base of the incline on the uphill side of the road. If some of these boulders have come from near the top of the cliff, their travel angles are unusually large. In general, the larger the mass of the rockfall, the farther it travels (the less the travel angle)
- there are no sandstone boulders on the downhill side of Harrison Way and none that I could see on the valley floor.
- any talus that may have existed there has long since been buried under soil from weathered shale, or washed away
- several of the boulders exhibit cavernous weathering, and one or two are honeycombed. This is due to salt weathering. The intensity and the geometry of this weathering, without exception, is consistent with it having occurred while the boulders are in their present positions relative to the sea and while in their present geographic

orientations. Some of the cavities are so deep that they must be hundreds of years old.

In general, in the absence of a talus or scree slope, the travel distance is limited by such factors as rockfall size, forest vegetation, terrain roughness, slope inclination, and so on.[5] However, at Harrison Way, another distinct possibility is that the travel distance down the slope was strongly limited by Harrison Way being at or below below sea level at the time the boulders fell, or in the surmised scenario, were being lowered by the decaying ice.

The MoTI quarry approach road

There is a similar set of massive boulders at a second site on Gabriola. It is on the NE side of the gravel approach road to the MoTI borrow pit[6] off South Road.

The sandstone boulders sit about 15 m from the crest of the scarp which extends all the way down to the sea. They extend upward from around 80 m ASL. The escarpment faces southwest, as does the scarp along Harrison Way. There is little to no sign of boulders lower down the slope. From the crest of the scarp, the land slopes gently away in a NE direction in *roche-moutonnée* fashion as required by the theory that the boulders were plucked from the cliff face by ice moving from the northeast.

View looking NE from the crest of the scarp along the approach road to the MoTI borrow pit. As expected if this were a *roche-moutonnée* feature, it slopes gently down in the direction the ice would have been coming from (the stoss side) in sharp contrast to the ruggedness of the scarp itself (the lee side).

The approach road has been built on a bench, and there is another bench about 20 metres wide higher up. Near the junction with South Road, at the same level as the lowest of the boulders, there is a 4–5 metre thick deposit of compacted undermelt till—a light-grey silt loam with ice-rafted

[5] The travel angle of a rockfall, also known as the "reach angle" and "travel distance angle", is the angle whose tangent is the vertical distance dropped divided by the horizontal distance travelled. The smaller the angle, the farther the rock debris has travelled by falling, rolling, and sliding away from its source on the cliff face. In BC, recorded travel angles of major rockfalls don't exceed 25°; yet, boulders falling from the height of Pat Burns Ave. would have had angles exceeding 40°. [Geertsema M. & Cruden D.M., *Travels in the Canadian Cordillera*, Proceedings of the 4th Canadian Conference on Geohazards, Presse de l'Université Laval, Québec, 2008].

High travel angles (40° average, less for rockfalls in excess of 100 m^3) have been associated with mature talus slopes that cushion the shock; however, there is no sign of a talus slope along Harrison Way. [Copons R., Vilaplana J.M., & Linares R., *Rockfall travel distance analysis by using empirical models (Sol`a d'Andorra la Vella, Central Pyrenees)*, Natural Hazards & Earth System Sciences, 9, pp. 2107–2118, 2009].

[6] BC Ministry of Transportation & Infrastructure, Degnen—0083. Central Island District 390–6100. The escarpment (Geoffrey Fm.) is part of the hinge associated with the apparent clockwise rotation of the Gulf Island coastline south of Gabriola. Although the bedrock at the south end of Gabriola participates in this rotation, the shoreline does not, and hence it transitions from older Northumberland Fm. (False Narrows lowland) to younger Geoffrey Fm. (east end of Stony Ridge) as you move east away from the axis of the Stuart Channel anticline.

dropstones. At one time, the approach road was below sea level, which is another plus for the ice-age theory.

Several of the boulders exhibit cavernous salt weathering similar to that seen at Harrison Way, and the geometry and orientation of the weathering is again consistent with it having occurred while the boulders are in their present positions. One cavity, still being actively weathered, is 1.2-m deep, which, given its position 0.8 km away from the sea and its being in forest shade, indicates that the weathering has been going on for a very long time, perhaps a thousand years or more.

Large sandstone boulders on the road to the MoTI pit off South Road. None have moved far from the cliff face, and many are delicately poised as if they had had little momentum when they settled into position. The cliff faces southwest, and the profile resembles the lee side of a *roche moutonnée* raising a suspicion that this may be what it is.

The boulders are angular, a consequence of them being released from the bedrock by near-vertical joints and erosion of near-horizontal bedding planes, especially along thin interlayers in the massive sandstone of laminated siltstone and silty-mudstone. In recent times, the erosion agents have been salt crystallization pressure and chemical weathering by groundwater seeping along the interlayers.

Shallow excavations under the perimeters of the boulders show the soil contains lots of sand and spalled case-hardened sandstone, which would again indicate salt-weathering has been on-going at this site.[7]

The travel angles of some of the boulders are not as high as those on Harrison Way (<34°), even though the boulders are smaller—the biggest is around 120 cubic metres—and the vertical fall onto one or other of the benches is less.

In recent geological times, there would also have been a substantial Douglas-fir forest here, which would have slowed rockfalls down and made travel angles higher. Some of the older stumps are 0.7 m or so in diameter.

Islands View Drive

Another good candidate for being the result of glaciation and not earthquakes is the the escarpment between Tyee Drive and Islands View Drive. These two roads run parallel,

[7] N.A. Doe, *Salt-weathering of upper Nanaimo Group sandstone*, *SHALE* 23, pp.35–56, March 2010. Also N.A. Doe, *What makes holes in sandstone*, *SHALE* 9, pp.12–40, August 2004.

with Tyee Drive about 25 metres higher than Islands View Drive at the western end. Most of this height difference is concentrated in the scarp at the back of the houses on Islands View Drive.

The scarp consists of very angular blocks of sandstone and faces southwest. In contrast, Tyee Drive and land to the NE, slopes away in a gentle manner. The geometry and orientation of the scarp is thus just as required for it to be the lee side of a *roche-moutonnée* created by a glacier moving from the northeast.

Angular blocks of sandstone at the base of the escarpment between Tyee Drive and Islands View Drive. The scarp faces southwest. Possibly these boulders were plucked from the cliff face during the last ice age and are not, as generally supposed, the result of a large earthquake.

One additional point of interest about this particular site is that one of the boulders near the base of the scarp carries a petroglyph (DgRw253), the orientation of which unmistakably indicates that the boulder has not moved very far since it was carved. This rules out the possibility that the boulder was brought down in the megathrust earthquake in 1700—the petroglyph is almost certainly hundreds of years older than that.

Other sites

Boulders at the bottom of cliffs are of course not unusual, and in many cases the normal processes of erosion is probably sufficient to explain them. Spring Beach, where large conglomerate boulders with travel angles of possibly up to 42° lie at present sea level, may be an example of one of these. In general though, the boulders at the bottom of cliffs tend to be much smaller than those along Harrison Way.

Conclusions

There is no conclusive evidence that the boulders along Harrison Way or on the approach road to the quarry were largely put there by plucking during the ice age, but it is quite possible that they were. Finding out what's underneath them (decayed vegetation and soil or sterile glacial gravel) could give as a clue as to their origin. ◊

Articles:

GD-533 Notes on fossil sites and radiocarbon dating
GD-534 Notes on sand deposits

Sea level changes.